THE EFFECT OF ORTHODONTIC BONDING SYSTEMS AND ACIDIC SOFT DRINKS ON MICROLEAKAGE USING CONFOCAL LASER SCANNING MICROSCOPY. AN *IN-VITRO* STUDY.

BY

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Dedication

To my Beloved Family

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List of abbreviations:

APC	Adhesive pre-coated brackets
Bis EMA	Bisphenol A glycol dimethacrylate
Bis GMA	Bisphenol- A glycidyl methacrylate
CAD-CAM	Computer-aided design - computer-aided manufacturing
CLSM	Confocal laser scanning microscope
HEMA	Hydroxyethyl methacrylate
ICC	Intra-class correlation coefficient
LEDs	Light emitting diode
NPG-GMA	N-phenylglycine and glycidyl methacrylate
QTH	Quartz tungsten- halogen
SEM	Scanning electron microscope
SS	Stainless steel

KESAN SISTEM PELEKAT ORTODONTIK DAN MINUMAN RINGAN BERASID KE ATAS MIKROBOCORAN MENGGUNAKAN MIKROSKOP IMBASAN LASER KONFOKAL. KAJIAN *IN-VITRO.*

ABSTRAK

Dekalsifikasi enamel di sekitar dan bawah dasar braket merupakan masalah besar. Mikrobocoran di bawah braket ortodontik boleh meningkatkan risiko dekalsifikasi enamel dan karies. Maklumat tentang mikrobocoran yang mungkin berlaku di bawah braket orthodontik melalui penggunaan pelbagai jenis bahan pelekat dan juga kesan minuman ringan berasid masih berkurangan.

Penyelidikan ini adalah bertujuan untuk membandingkan tahap mikrobocoran antara sistem ikatan orthodontik konvensional dan sistem ikatan ortodontik terintegrasi dan pengaruh minuman ringan berasid ke atas mikrobocoran. Sebanyak 80 batang gigi premolar atas kekal digunakan. Sisa-sisa tisu yang ketara pada akar gigi telah dibuang dan permukaan bukal dilicinkan. Gigi secara rawak dibahagikan sama rata kepada empat kumpulan. Kumpulan 1 dan Kumpulan 3 diikat secara sistem ikatan konvensional (Punaran primer dua-langkah + pelekat + braket logam). Kumpulan 2 dan Kumpulan 4 diikat secara sistem ikatan terintegrasi (Primer punaran-kendiri + braket pra-dilapisi pelekat). Kemudian semua gigi direndam di dalam air suling selama 4 minggu. Setelah itu, gigi kumpulan 3 dan 4 direndam pula di dalam minuman ringan berasid (Coca-Cola ®) selama 24 jam. Apeks gigi kemudian disalut dengan lilin lekit dan dicat dengan cat kuku, kecuali untuk 1-mm sekitar braket dan kemudian dimasukkan ke dalam 0.5% pewarna Rhodamin B. Setelah 24 jam, gigi

dicuci dan dipasang pada blok resin akrilik. Setiap gigi kemudian dipotong membujur dalam arah bukalingual menghasilkan tiga permukaan yang boleh diperiksa. Mikrobocoran diperiksa di bawah mikroskop konfokal laser bagi setiap permukaan. Mikrobocoran di dalam antara muka pelekat-enamel dan antara muka pelekat-braket diukur di bawah alat penganalisa imej digital yang telah dikalibrasi. Data dianalisa menggunakan perisian SPSS dan ujian-t digunakan untuk perbandingan.

Kumpulan 2 menunjukkan purata mikrobocoran yang lebih tinggi berbanding Kumpulan 1 di dalam antara muka pelekat-enamel (P= 0.003) dan antara muka pelekat-braket (P= 0.018). Kumpulan 3 menunjukkan purata mikrobocoran yang lebih tinggi daripada Kumpulan 1 di dalam antara muka pelekat-enamel (P= 0.003). Namun, tidak ada perbezaan yang signifikan dalam antara muka pelekat-braket (P= 0.055). Demikian juga, tidak ada perbezaan yang signifikan di antara Kumpulan 2 dan Kumpulan 4 di dalam antara muka pelekat-enamel (P= 0.15) atau antara muka pelekat-braket (P= 0.79). Keputusan kajian menunjukkan tidak ada perbezaan mikrobocoran yang signifikan di antara servikal dan oklusal dalam semua kumpulan.

Sebagai kesimpulan, sistem ikatan konvensional telah menunjukkan mikrobocoran yang lebih rendah daripada sistem ikatan terintegrasi di dalam kedua-dua antara muka. Minuman ringan berasid meningkatkan mikrobocoran bagi sistem ikatan konvensional di dalam antara muka pelekat-enamel.

THE EFFECT OF ORTHODONTIC BONDING SYSTEMS AND ACIDIC SOFT DRINKS ON MICROLEAKAGE USING CONFOCAL LASER SCANNING MICROSCOPY. AN *IN-VITRO* STUDY.

ABSTRACT

Enamel decalcification around and under the bracket base is a considerable problem. Microleakage under the orthodontic brackets increases the risk of decalcification and caries. There is a lack of information about microleakage that may occur under the orthodontic bracket when different types of adhesive are used and how it is affected by acidic soft drinks.

The purpose of this study was to compare the degree of microleakage between the conventional orthodontic bonding system and integrated orthodontic bonding system and the effect of acidic soft drinks on microleakage at the cervical and occlusal region. A total of 80 sound upper permanent premolar teeth were used. Obvious tissue remnants on the roots were removed and the buccal surfaces were polished. The teeth were randomly divided into four equal groups. Group 1 and Group 3 were bonded with conventional bonding system (Two-step etching primer + Adhesive + Metal bracket). Group 2 and Group 4 were bonded with integrated bonding system (Self-etching primer + Adhesive pre-coated bracket). The teeth of all groups were stored in distilled water for 4 weeks. After that, teeth of group 3 and 4 were further stored in acidic soft drink (Coca-Cola® drink) for 24 hours. The apices of the teeth were then sealed with sticky wax and painted with nail varnish except for 1-mm around the bracket and then placed in 0.5% Rhodamine B dye. After 24 hours, teeth were washed and mounted in clear acrylic resin blocks. Each tooth was then cut longitudinally in the buccolingual direction producing three examinable surfaces. Each surface was examined for microleakage under confocal laser scanning microscope. Microleakage in the enamel-adhesive interface and the adhesive-bracket interface were then measured under the digital calibrated image analyzer. Data was analyzed by using SPSS software and independent t-test was used for comparison. $P < 0.05$ is considered statistically significant.

Group 2 showed significantly higher mean microleakage than Group 1 in the enamel-adhesive interface ($P=0.003$) and adhesive-bracket interface ($P=0.018$). Group 3 showed significantly higher mean microleakage than Group 1 in the enamel-adhesive interface $P=0.003$. However, there was no significant difference in the adhesive-bracket interface ($P =0.055$). Finally, there was no significant difference in between Group 2 and Group 4 in the enamel-adhesive ($P=0.15$) or the adhesive-bracket interface $P=0.79$. The results showed no significant differences between cervical and occlusal microleakage in all groups.

In conclusion, conventional bonding system had lower microleakage than the integrated bonding system in both interfaces. Acidic soft drinks increased microleakage in the conventional bonding system in the enamel-adhesive interface.

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

1.1.1 Microleakage

Microleakage is defined as the seeping and leaking of fluids and bacteria between the tooth or restoration junction and interface. In orthodontics, microleakage can occur between the enamel and adhesive or between the adhesive and bracket. A pathway of microleakage between the tooth structure and adhesive leaves the possibility for microbial access resulting in enamel decalcification and caries (Gillgrass *et al*., 1999; James *et al*., 2003). The increased risk of microleakage is primarily due to polymerization shrinkage of the adhesive, which is one of the major disadvantages of adhesives materials (James *et al*., 2003; Arhun *et al.*, 2006; Arikan *et al*., 2006,). Microleakage may also result from other factors such as dissolution of linear or smear layers, degradation of the particular bonding or restorative material, the difference in the coefficients of thermal expansion between the tooth structure and restorations (Attar *et al*., 2007), or the type of adhesive and bracket used (Arhun *et al*., 2006). Having a strong bond between the tooth structure and adhesive decreases or even may eliminate microleakage (Cannon, 2003).

Enamel decalcification around and under the orthodontic bracket is a substantial problem, predominantly in patients with poor oral hygiene. Shrinkage of the composite adhesive upon curing will cause a gap between the adhesive material and enamel surface leading to microleakage, thus facilitating the development of white-spot lesions under the bracket surface area. This gap can cover an area of 10 mm^2 in the enamel-adhesive interface in which oral fluids leaking and bacterial accumulation were consistently observed (Sukontapatipark *et al*., 2001). The organic acids produced by bacteria may lead to demineralization of the enamel, which occurs when the pH is low enough to favor diffusion of calcium and phosphate ions out of enamel (O'Reilly and Featherstone, 1987). In addition, the rough surface of the remaining adhesive on the enamel surface also provides sites for the rapid attachment and growth of oral microorganisms (Armstrong *et al*., 1998).

Demineralization of enamel has been found in as many as 50% of teeth treated with bonded orthodontic brackets and in up to 50% of orthodontic patients (Gorelick *et al.*, 1982). Other studies showed that an average of two out of three teeth bonded with orthodontic fixed appliances was affected by some form of enamel opacity after the orthodontic treatment. The recorded opacities covered an average of less than one-third of the labial surface (Nunn *et al*., 1993; Nunn *et al.*, 1994). Furthermore, O'Reilly and Featherstone (1987) reported that considerable decalcification areas were perceived around the orthodontic appliances after only 1 month of treatment with fixed orthodontic appliances. Øgaard (1989) showed that an aesthetic problem may be present as much as five years after treatment. In addition, a previous study showed that microleakage had significant effects on the durability of bonding (Celiberti and Lussi, 2005). This was particularly expressed in the enamel-adhesive interface more than the adhesive-bracket interface (Uysal *et al*., 2008). All of these findings support that the demineralization of the teeth during orthodontic therapy is an imperative clinical problem.

1.1.2 Adhesive materials in orthodontics

Nowadays, the search for improved adhesive and resin composite materials has received considerable interest. The orthodontists had implemented the new advancements in the development of adhesive dentistry and added them to their arsenal. Tooth conserving and time saving adhesive methods of retaining orthodontic attachments are replacing conventional methods and procedures. The most important factors for this popularity are longer material working time and flexibility in initiating the polymerization process, which means extended bracket positioning time (Greenlaw *et al*., 1989; Oesterle *et al*., 2002; Arıkan *et al*., 2006). According to Pettemerides *et al.* (2004), the reduced bonding time would have a number of advantages :

1- Increased comfort for the patient.
2- Less chance of bracket drift prior to curing.
3- Less time for moisture contamination.
4- Less stress for the operator.
5- Cost saving.

Although the advantages are revolutionary, yet these new innovations must not come on the cost of having an effective and reliable bond between the orthodontic bracket and the tooth. In orthodontic practice, it is essential to obtain a reliable bond between orthodontic brackets and tooth enamel to ensure a healthy caries free treatment procedure (Grubisa *et al.*, 2004).

One of the main new advancements in adhesive dentistry is bonding the orthodontic attachments to tooth material without the acid etching step. The self-etching system has been recently introduced to the market. The aim is to reduce and simplify bonding procedures, chair time and technique sensitivity by reducing the number of clinical steps involved (Romano *et al.*, 2005). Unsurprisingly, its recognition and popularity is growing.

Besides the reduced technique sensitivity and chair time, the use of single-step, self-etching one-component adhesives may prevent the discrepancies occurring between the depth of etching and resin monomer penetration. This is because the self-etching system forms a continuous layer by simultaneous demineralization with acidic monomers, followed by resin monomer penetration into the demineralized tooth structure (Van Meerbeek *et al.*, 2003).

Tests done on the self-etching system have showed adequate bond to the conditioned dentin, nevertheless, the bond to enamel was less competent (Kugel and Ferrari, 2000). One of the causes could be the insufficient etching of the enamel. Besides, this system was first provided in two bottles by which a drop of liquid from each bottle is mixed together before application. This was considered to be a source of error as the manual handling can produce an unequal ratio of liquid mixture. Therefore, manufacturers introduced adhesive systems which combined the two liquids in one bottle, as a further step in improving the procedure.

Application of self-etching system on enamel has been a controversial issue. On the one hand, Hara *et al*. (1999) reported that bonding of self-etching adhesives to ground enamel was inferior when compared with multiple steps adhesive, or total-etch system that utilizes phosphoric acid as a separate conditioner. On the other hand, studies showed that self-etching systems might be used as a satisfactory alternative to phosphoric acid conditioning of ground enamel (Blunck and Roulet, 1999; Hannig *et al.*, 1999).

1.1.3 Acidic soft drinks and oral problems

Soft drink consumption has steadily increased in recent decades in both developed and developing countries. The trend is most apparent among children and adolescents. From year 1990 to year 2000, the commercial sale of soft drinks has increased by over 56% and is estimated that they keep rising for more than 3% every year (West *et al*., 2000). The daily requirement water for an average man is 2–3 liters. In Western countries, more than half of this amount comes from soft drinks. Consequently, in these societies the use of milk as a main source of liquid for children is on the way out at the same time as consumers drink greater amounts of soft drinks, including fruit juices and carbonated beverages (Sorvari and Rytomaa, 1991; He *et al.,* 2008).

This rise in soft drink consumption has raised concerns among health care professionals, including dental practitioners. The effects of soft drinks on dental health have been investigated. Accordingly, several studies have shown that dental problems such as caries, enamel erosion, and corrosion of dental materials, may be associated with soft drink consumption (Rytomaa *et al.*, 1988; Meurman and Frank, 1991; Grando *et al.*, 1996). Interestingly, the age groups with the highest consumption of acidic soft drinks are children and adolescents (He *et al.*, 2008), which are the age groups of most orthodontic patients. Since orthodontic appliances restrict toothbrush access, patients undergoing orthodontic treatment may possibly be the most affected by the adverse effects of acidic soft drinks.

Children have greater susceptibility to enamel dissolution (Tahmassebi *et al*., 2006). Enamel in children is young, immature and porous which make it dissolve more easily by acids until the final intra-oral maturation of the surface enamel has occurred (Weatherell *et al*., 1984). Normally as the immature enamel is submersed by salivary ions, it becomes less penetrable, gradually harder, and quite resistant to acid attack (Margolis *et al*., 1986). Nevertheless, enamel maturation is completed over big time lap and for this reason; young children are at greater threat of dental caries if the acidogenic challenges is too much. That is why the concern about soft drinks and its relation to dental health is largely focused on children, specially that most of the orthodontic patients are children.

The damage caused by acidic soft drinks to the teeth has been suggested for two reasons. Firstly, the plaque microorganisms metabolize the sugars in drinks generating organic acids that may result in demineralization leading to dental caries. Secondly the high acidity (low pH) of various drinks may lead to erosion of the enamel surface. The low pH value of the soft drinks is thought to be the main cause of its erosive characteristics (Tahmassebi *et al*., 2006). This erosion occurs as a loss of the outermost surface of enamel and result when the surface pH falls below 5.5 (Zero, 1996).

The low pH value of soft drinks may be contributed by several types of acids in the drinks. Some may be intrinsic and derived from the natural components used in manufacture. During the manufacturing process other acids will take place which are considered to improve properties of the drink, such as carbonation. Carbonated beverages will contain carbonic acid formed by carbon dioxide in solution. Even when the carbon dioxide has been blown off and the drink has become plain and free from its fizzy characteristic, the pH still remains low (Grobler and van der Horst, 1982). This shows that the acquired acidity of the soft drinks is attributed to other acids that are added to stimulate taste. These other acids include carbonic acid under pressure to produce a sparkling drink, as well as phosphoric, citric acids and other acids that are present in cola-type drinks to provide flavor (Birkhed, 1984).

1.1.4 Confocal Laser Scanning Microscope

Previous studies carried out microleakage testing by using normal low-resolution optical microscopy with fluorescent dyes since these dyes present a very visible, strong color (Brunton *et al.* 2004; Arhun *et al.*, 2006; Yagci *et al.*, 2009). Nevertheless, the introduction of confocal laser scanning microscope (CLSM) took microleakage testing to a new level far advanced than conventional microscopy.

CLSM offers a number of advantages over conventional optical microscopy. This includes the capability to control depth of field as well as the reduction or even eradication of background information away from the focal plane that leads to image degradation. It also has the advantage of being capable to collect serialized optical sections from thick solid specimens. This technique generates significant improvement in resolution, consequently, accuracy, lying somewhere between conventional light microscope and scanning electron microscope (SEM). Besides, this type of microscopy enables high resolution images to be made of samples with minimum requirements for specimen preparation (Watson, 1997). Therefore, CLSM may provide more accurate detection of microleakage (D'Alpino *et al.*, 2006a). For all these reasons, this technology was utilized to detect microleakage in this study.

1.2 Statement of Problem

Enamel decalcification around and under the bracket base is a considerable problem since microleakage under the orthodontic brackets increases the risk of decalcification and caries (O'Reilly and Featherstone, 1987). Studies showed that microleakage had a significant effect on the durability of bonding (Celiberti and Lussi, 2005). Additionally, enamel demineralization under and around the orthodontic bracket has been reported to be observed (Nunn *et al.*, 1993; 1994) after one month of treatment with fixed orthodontic appliances (O'Reilly and Featherstone, 1987) and may cause an aesthetic problem after five years of orthodontic treatment (Øgaard, 1989). Therefore, findings from the literature support that the demineralization of the teeth during orthodontic therapy is a problem of clinical importance.

There is a lack of information about the microleakage that may occur under the orthodontic bracket when different types of adhesives are used (Arhun *et al*., 2006). Furthermore, despite the disparaging nature that the acidic soft drinks have on enamel, so far to our knowledge, there have been only one study reported investigating its effects on microleakage (Navarro *et al.*, 2010). However, this study investigated the effect of soft drinks on only one type of adhesive primer and orthodontic bracket. Furthermore, the specimens used were not human teeth.

This study will determine which type of the tested adhesive primers and orthodontic metal brackets exhibits more microleakage. Furthermore, the effect of acidic soft drinks on microleakage will be determined and which type of the tested adhesive primers and metal orthodontic brackets are more resistant to microleakage in acidic soft drinks.

The results of the study may provide orthodontists and dental health service providers with some knowledge that will assist them select better orthodontic bonding systems in order to provide longer lasting caries free treatment to their patients.

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1.3 Objectives

1.3.1 General Objective:

To study microleakage under the orthodontic bracket bonded with conventional orthodontic bonding system and integrated orthodontic bonding system and the effect of acidic soft drinks to both techniques on microleakage.

1.3.2 Specific Objectives:

1. To determine and compare the degree of microleakage in the enamel-adhesive interface when using the conventional bonding system and integrated bonding system.

2. To determine and compare the degree of microleakage in the adhesive-bracket interface when using the conventional bonding system and integrated bonding system.

3. To determine the effect of acidic soft drinks on microleakage in the enamel-adhesive interface and adhesive-bracket interface when using integrated bonding system.

4. To determine the effect of acidic soft drinks on microleakage in the enamel-adhesive interface and adhesive-bracket interface when using conventional bonding system.

5. To determine the difference in the degree of microleakage between the cervical and occlusal directions in all groups.

1.4 Null hypothesis

1. There is no significant difference in the degree of microleakage in the enamel-adhesive interface when using the conventional bonding system and integrated bonding system.

2. There is no significant difference in the degree of microleakage in the adhesive-bracket interface when using the integrated bonding system and conventional bonding system.

3. Acidic soft drinks have no effect on microleakage in the enamel-adhesive interface or adhesive-bracket interface when using the integrated bonding system.

4. Acidic soft drinks have no effect on microleakage in the enamel-adhesive interface or adhesive-bracket interface when using conventional bonding system.

5. There is no difference in the degree of microleakage between the cervical and occlusal direction in all groups

CHAPTER TWO

LITERATURE REVIEW

2.1 The orthodontic fixed bracket appliances

Orthodontic fixed bracket appliance are defined as a device that projects horizontally to support auxiliaries and is open one side usually in vertical or horizontal. Orthodontic brackets are an essential component of modern fixed appliances. They are manufactured and designed to deliver the exact force from the wire to the teeth. In order to do so, brackets should have the design, hardness and strength (Feldner *et al.*, 1994; Flores *et al.*, 1994).

Edward Angle, also known as “the father of orthodontics”, was the first to create the orthodontic fixed bracket appliance. With few exceptions, until today the fixed appliances used in modern orthodontics are based on Angle's designs from the early 20th century. Angle had developed four major appliance systems (Proffit *et al.*, 2007) as discussed in the following.

2.1.1 Obsolete appliances

In the late 1800s, Angle developed a distinctive orthodontic appliance that consisted of some sort of rigid framework to which the teeth were tied. This appliance, the E-arch, was an improvement of Angle's first basic. The capability of the E-arch appliance was limited; it could not accurately position any tooth individually (Proffit *et al.*, 2007). Angle's next appliance modified the tube on each tooth to provide a vertically positioned rectangular slot behind the tube. A ribbon arch wire was placed into the slot and held with pins. The ribbon arch was an immediate success, primarily because the archwire, unlike any of its predecessors, was small enough to have good spring qualities and was quite efficient in aligning malpositioned teeth. The resiliency of the ribbon archwire simply did not allow the generation of the moments necessary to torque roots to a new position (Proffit *et al.*, 2007).

2.1.2 Edgewise appliance

In an attempt to overcome the deficiencies of the ribbon arch appliance, Angle reoriented the slot from vertical to horizontal and inserted a rectangular wire rotated 90 degrees to the direction it had with the ribbon arch and so, he named it "edgewise" . The new dimension of the edgewise bracket allowed excellent control of crown and root position in all three planes of space. After its introduction in 1928, this appliance became the mainstay of multibanded fixed appliance therapy (Proffit *et al.*, 2007).

2.1.3 The pre-adjusted appliance

Until the mid 1970s, most fixed appliance orthodontic therapies were carried out using the standard edgewise appliance which has a 90° bracket base and bracket slot angulations. Archwire bending by the orthodontist was required in order to achieve adequate results. Two major disadvantages resulted from this treatment method. Firstly, archwire bending was time consuming and tedious. Secondly, the shortcoming of the bracket system and the extreme skill required from the orthodontist, resulted in many undertreated cases (Bennett and McLaughlin, 1993).

Against this background, Lawrence F. Andrews created the pre-adjusted appliance. The concept of the pre-adjusted appliance is changing the 90° bracket base and bracket slot angulations to different angulations (according to the tooth) to achieve the desired tooth position with minimal or no wire bending at all. It was appreciated by orthodontists as a radical step forward, offering the dual advantage of less wire bending coupled with an improved quality of finished cases (Bennett and McLaughlin, 1993). Later, the prescription in the built-in bracket adjustments changed. This is because the prescription in the built-in bracket adjustments suggested by the manufacturers and clinicians are based on the individual practitioner's preference. As a result numerous variations exist in the market (Bishara, 2001).

Many efforts have been made since 1909 to improve orthodontic brackets. Ceramic and plastic have been introduced, but both have shown significant disadvantages when used for orthodontic therapy. Plastic brackets (Feldner *et al.*, 1994) were found to be easily discolored by water absorption and to have low deformation resistance to high applied torque. Ceramics brackets (Arici and Regan, 1997) were proved to be too brittle and the part of the enamel layer bound by adhesive tended to be detached with the ceramic bracket when the bracket was removed from the teeth. However, metallic orthodontic brackets have demonstrated properties that are closer to the ideal, and have been used most frequently for fixed orthodontic treatment (Creekmore and Kunik, 1993).

The majority of metal brackets are made from stainless steel (SS). Deguchi *et al.* (1996) reported on the properties of an experimental bracket made of titanium, and the corrosion behavior of brackets made of 2205 duplex SS has also been studied. The recycling of brackets has been attempted in the past, and while Wheeler and Ackerman (1983) reported that the bond strength did not decrease, Maijer and Smith (1982) presented contradictory results showing that bond strength and corrosion resistance were markedly decreased.Currently, most orthodontic bracket appliances are made from AISI type 304L SS. Such steel contains 18-20% chromium and 8-10% nickel with a small amount of manganese and silicon, and has low carbon content, typically less than 0.03%.

However, localized corrosion of these materials can frequently occur in the oral cavity due to their low corrosion resistance in a solution containing chloride ions like saliva. This lead manufacturers to produce the Super SS which has localized corrosion resistance that is as good as the titanium alloys. This is because its passive film is enhanced by the effect of high concentrations of nitrogen (0.331 %) and molybdenum (6.77 %). It also has good mechanical properties which are thought to allow the material to minimize the amount of metal ions released in the oral environment (Oh *et al.*, 2005).

In 1991, metal brackets have been pre-coated with composite resin in an attempt to save chair-time by reducing the number of steps in the bonding procedures, and in that way, reducing the number of bonding variables (Hirani and Sherriff, 2006). This approach also provides a more uniform thickness of the adhesive. This type of bracket is known as Adhesive Pre-coated Brackets (APCs) and has advantages over conventional brackets that can be listed as follows (Cal-Neto *et al.*, 2006):

1. Consistent quality and quantity of adhesive
2. Easier cleanup after bonding
3. Improved asepsis
4. Reduced waste during bonding, and
5. Better inventory control

Previous studies implied that metallic APCs have lower shear bond strength than manually placed composite resin (Transbond XT, 3M Unitek, USA) on uncoated metal brackets (Bishara *et al.*, 1997). As a result, the manufacturer has dealt with this setback by modifying the adhesive used for pre-coating and upgrading APC to APC II (Hirani and Sherriff, 2006). The various ingredients of the adhesive applied to the pre-coated brackets APC and APC II as well as that in the Transbond XT adhesive are presented in Table 2.1. The differences are basically limited to the percentages of the integrated ingredients rather than in the chemical composition of the adhesive itself. The Transbond XT precisely contains 14% Bis GMA, 9% Bis EMA, and 77% fillers

(Silylated quartz and sub-micron Silica). On the other hand, the corresponding values for the APC adhesive used on the precoated brackets are 12%, 8% and 80% respectively. As for the APC II, the percentage of the ingredients were identical to those in Transbond XT (Bishara *et al.,* 2002).

Table 2.1 Composition of the adhesive in Transbond XT, APC II and APC

Raw Material	Transbond XT	APC II	APC
Resins			
BisGMA	14%	14%	12%
BisEMA	9%	9%	8%
Fillers			
Silylated quartz *Silylated filler and submicron silica*	77%	77%	88%
Curatives			
Camphorquinone	<1%	<1%	<1%
Others	<1%	<1%	<1%

The new modification in the composition of the adhesive reduced its viscosity. This allowed the bracket to be controlled more readily and easily on the tooth surface throughout the early stages of bracket positioning. As a result, APC II and Transbond XT adhesive had relatively softer consistency than the original APC, thus making it easier for the clinician to place, press and adjust the bracket on the tooth surface during the bonding procedures (Bishara *et al.,* 2002).

2.2 Adhesive system

Adhesion is a term that describes the attachment of one substance to another when they are into close contact with each other. According to Blunck (2000), it is defined as the force that binds dissimilar materials together when they are brought into intimate contact. In order to obtain a better contact between the two materials, an intermediate layer, called an adhesive has to be placed.

In the late 1960s, Buonocore *et al.* (1968) explained that the principal adhesion of the resins to acid-etched enamel is caused by the formation of resin tags. The theory was that resin penetrates the micro-porosities of etched enamel and results in a micromechanical between the tooth structure and resin. This theory is well-accepted today.

As time went on, variations in the duration of the acid-etching procedure and concentration of the phosphoric acid, along with alternative acids, were tested for the etching of enamel (Silverstone, 1974; Barkmeier *et al.*, 1985). Furthermore, many improvements have occurred in the formulation and techniques of adhesives and composites which revolutionized adhesive dentistry. Recently, the extensive search for adhesive systems with simpler procedures and less technique sensitivity along with the growing popularity of simplified self-etch adhesive systems has led to the invention of self-etch, one-step, one-component adhesive system. In this adhesive system, the etching, priming and bonding solutions are combined and mixed in one bottle to become one solution. Based on this combination, this adhesive system can accomplish etching, priming and bonding simultaneously to enamel and dentin immediately after dispensing (Pashley and Tay, 2001).

The application of 30% to 40% phosphoric acid removes about 10 microns of the enamel surface, producing a partially dissolved enamel rods in a depth of 10-20 microns. The etching procedure also results in a rough surface which considerably increases surface area. This effect results in adhesive wettability that increase and allow the adhesive to get into intimate contact with the enamel surface, and forming micromechanical interlock to the tooth material (Peschke *et al*., 2000).

However, the ultra structure of the resin-enamel interface in phosphoric acid-etched uncut enamel, remains the most variable and by far the most difficult to understand such as the case of bracket bonding. This is due to the presence of aprismatic and prismatic etching features together in the same interface (Tay *et al*., 1996).

2.2.1 Dental adhesives classification

Several classifications have been suggested to classify dental adhesives, scientifically these classifications are:

1. Chronologically based classification
2. Clinical approach classification
3. Solvent based classification

2.2.1.1 Chronologically based classification

The fundamental of this classification is generally the time that adhesive system was introduced to market. Currently, seven generations of adhesive systems have been released, these generations are as follows:

2.2.1.1.1 First generation adhesive system

In 1956, Buonocore *et al.* demonstrated that the use of a glycerophosphoric acid dimethacrylate-containing resin would bond to acid-etched dentin. This bond was believed to be due to the interaction of this bifunctional resin molecule with the calcium ions of hydroxyapatite. Of course, immersion in water would greatly reduce this bond. Nine years later Bowen (1965) tried to address this subject using N-phenylglycine and glycidyl methacrylate (NPG-GMA). NPG-GMA is a bi-functional molecule or coupling agent. This means that one end of this molecule bond to dentin and the other bonds (polymerizes) to composite resin. However, this system showed poor clinical results in terms of durability.

2.2.1.1.2 Second generation adhesive system

In late 1970s, the second generation system was introduced. The majority of these included halophosphorous esters of unfilled resins such as bisphenol- A glycidyl methacrylate, or bis-GMA, or hydroxyethyl methacrylate, or HEMA. The mechanism by which the second generation system bonded to dentin was postulated to be through an ionic bond to calcium by chlorophosphate groups. This was considered weak bonds in comparison with later generation systems. Bonding to the smear layer was the major source of retention for this system and even some of the second generation system was thought to soften the smear layer and thus improve resin penetration. However, this system resulted in weak bond strength (Kugel and Ferrari, 2000).

2.2.1.1.3 Third generation adhesive system

The third generation system was introduced by Fusayama *et al*. (1979). The main principle was to acid etch dentin with phosphoric before the application of phosphate ester-type adhesive system. The etching of the dentin will partially remove and/or modify the smear layer; it will open the dentinal tubules partially and increase their permeability (Fusayama *et al.*, 1979). The acid must be rinsed completely before the primer is applied. The primers contained a hydrophilic group that infiltrates the smear layer, modifying it and promoting adhesion to dentin, and the hydrophilic group of the primer creates adhesion to the resin. Following primer application, an unfilled resin is placed on dentin and enamel. In this system, the phosphate primer modifies the smear layer by softening it; after penetration, it cures, forming a hard surface.

One of the major concerns with this system was that the phosphate bond to calcium in the dentin was not strong enough to resist the hydrolysis resulting from water immersion. This hydrolysis, from either saliva exposure or moisture from the dentin itself, could result in composite resin debonding from the dentin and causing microleakage (Tao *et al.*, 1988).

2.2.1.1.4 Fourth generation adhesive system

The main concept behind the fourth generation bonding system is to completely remove the smear layer. Fusayama *et al.* (1979) tried to simplify bonding to enamel and dentin by etching the preparation with 40 percent phosphoric acid. Unfortunately, over etching dentin resulted in the collapse of exposed collagen fibers. Nakabayashi *et al*. (1982) had reported the formation of a hybrid layer resulting from the polymerized methacrylate and dentin. The main characteristic of the fourth generation bonding system is the use of total-etch technique (Kanca, 1991; Gwinnett, 1993). The total-etch technique permits the etching of enamel and dentin simultaneously using phosphoric acid for 15 to 20 seconds. The fourth generation adhesive is basically composed of:

a) Acid etching gel that is rinsed off.

b) Reactive hydrophilic monomers in a solvent as a primer solution.

c) Hydrophobic bonding agent (filled or unfilled).

2.2.1.1.5 Fifth generation adhesive system

To simplify the clinical procedure by reducing the bonding steps and thus, the working time, a better system was needed. Also, clinicians needed a better way to prevent collagen collapse of demineralized dentin. In the fifth generation, the primer and bonding agent steps are merged into one step. The fifth generation adhesive system can be divided into two different types, the one-bottle system and the self-etching primer bonding system.

a) One-bottle system

For clinical use assistance, "one-bottle systems" shared the adhesives and primer into one solution to be applied after the simultaneous etching of enamel and dentin with 35 to 37 percent phosphoric acid for 15 to 20 seconds (Ferrari *et al.*, 1997a). In this bonding system, mechanical interlocking with etched dentin is achieved by means of resin tags, adhesive lateral branches and hybrid layer formation. They show high bond strength values for the etched enamel and dentin (Tay *et al.*, 1994).

b) Self-etching primer bonding system

In 1993, Watanabe and Nakabayashi developed a self-etching primer that was used for bonding to enamel and dentin at the same time. It was composed of an aqueous solution of 20 percent phenyl-P in 30 percent HEMA (Watanabe and Nakabayashi, 1993). The elimination of acidic gel washing reduced the working time. Another advantage was that the possibility of collagen collapse was eliminated by uniting the etching and priming steps into one step.

The self-etching primer solution, nevertheless, has some drawbacks. Firstly, residual smear layer often remains separating adhesive material and dentin (Kugel, 2000). Secondly, the solution must be refreshed constantly because its liquid formulation cannot be controlled where it is placed (Ferrari *et al.*, 1997b; Kugel, 2000). Clinical conditions showed that the seal achieved at the enamel margins with one-bottle systems is superior to that resulting from self-etching primer (Ferrari *et al.*, 1997b).

2.2.1.1.6 Sixth generation adhesive system

The sixth generation adhesive system consisted of two bottles; one for hydrophilic component whiles the other for hydrophobic component and phosphoric acid. Before being applied to the tooth structure, these two liquids are mixed with each other in a plastic mixing well. The first evaluations of this new system showed adequate bond